BARRELLING TEST OF T-SECTION ALUMINIUM BILLET AT ROOM TEMPERATURE

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In partial fulfilment of the requirements
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By

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ODISHA

CERTIFICATE

This is to certify that thesis entitled, "**BARRELLING TEST OF T-SECTION ALUMINIUM BILLET AT ROOM TEMPERATURE"** submitted by Mr. Gourav Choudhury in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any other Degree or Diploma.

Date: 6th May, 2014

Place: Rourkela

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Date: 6th May, 2014

Place: Rourkela

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Mechanical engineering

CONTENT

ABSTRACT

During Compression Testing, a solid specimen (T in Cross-Section) is compressed axially between the punch and the bottom plates. As a result of this, the work piece material undergoes compression along with deformation which basically is ***Bulging*** at its centre position.

In ***Compression or Upsetting***, the presence of frictional constraints between the dies and the work piece directly affects the plastic deformation of the work piece. The friction at the faces of contact retards the plastic flow of metals around the surface and in its vicinity. A conical wedge of a relatively un-deformed metal is formed directly below it while the rest of the cylindrical metal suffers high strain hardening and subsequently bulges out. However, in practice, the use of lubricants greatly reduces the degree of bulging to a great extent. Hence it is necessary to apply a correction factor for the purpose of bulging design of die. For a ductile material like Aluminium used here lateral distortion takes place and due to restraining influence of friction of the load faces, the cross section becomes greater at the centre, the test piece taking up a barrel shape. Hence this is termed as ***Barrelling***.

In this particular experimentation the object geometry of Aluminium specimen under different percentage deformation is recorded and the barrelling radius is calculated under the assumption that T-section billet can be considered as summation of rectangular and square billet placed perpendicular to each other. A relation between percentage deformation and the barrelling radius of the T-section specimen is obtained.

LIST OF FIGURES & GRAPHS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Metal Forging

Metal forging [1] is a type of metal forming process where compressive loads are applied to deform the work piece so as to give the desired geometrical shape to any material. It is an important process in industries, especially in iron and steel industries. Material properties are often greatly improved in forging process.

Forging is known to produce some of the strongest manufactured parts compared to other metal manufacturing processes but is not just limited to iron and steel forging but to other metals too. Different metals will have a different types of factors involved when forging them, while some will be easier to forge others might not. Aluminium, titanium, copper, magnesium, and nickel along with iron and steel are commonly forged metals. Forging of metals can strengthen the metal by various ways. It seals off cracks and closes empty spaces within the metal structure. Metal's grain structure is also modified with respect to flow of material during deformation which creates favourable grain structure in a material greatly increasing the strength of forged parts.

Forging manufactured products in today's industry include critical aeroplane parts such as shafts for jet engines and turbines, landing gears, structural components of automobiles and railways such as levers, gears, connecting rods, crankshafts hand held tools such as rivets, screws, chisels and bolts etc. Once set up, forging operation costs can be relatively low, and mostly all parts of process can be automated. All these factors make manufacturing using metal forgings economically beneficial.

Classification of metal forging processes is based on the amount of material flow constrained during the process. There are three major classifications in metal forging manufacture. First, **open die forging**, in which the work is compressed between two die that do not constrain the metal during the process. Secondly, **impression die forging**, in which cavities within the die restrict metal flow during the compression of the part, causing the material to deform into a desired geometric shape. Some material in impression die forging is not constrained by the cavities and flows outward from the die, this metal is called flash. In industrial metal forging, a subsequent trimming operation will be performed to remove the flash. The third type of metal forging is **flashless forging**. In flash less forging manufacture the entire work piece is contained within the die in such a way that no metal can flow out of the die cavity during the compression of the part, hence no flash is produced.

Open Die forging

The manufacturing process of metal forging has been performed for at least 7,000 years, perhaps even 10,000 years. The most basic type of forging would have been shaping some metal by striking it with a rock. Latter the employment of different materials, such as bronze then iron and steel, and the need for forged metal products such as swords and armour, led way to the art of blacksmithing or blacksmith forging. Blacksmithing is an open die forging process where the hammer and anvil surfaces serve as opposing flat die. Bronze forgings, followed by iron and steel forgings, mark some of man's earlier manufacturing prowess.

A simple type of open die forging is called upsetting. In an upsetting process the work is placed between two flat die and its height is decreased by compressive forces exerted between the two die. Since the volume of a metal will remain constant throughout its deformation, a reduction in height will be accompanied by an increase in width. Below figure shows a flat die upsetting process, under ideal conditions.

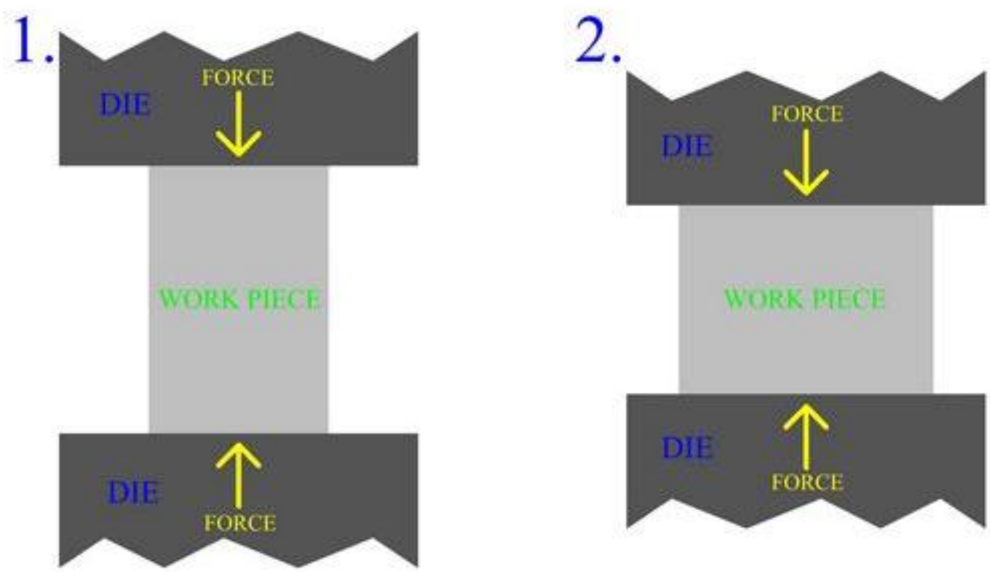


FIG 1. Upsetting in flat die forging under ideal conditions

In real conditions during industrial manufacturing, friction plays a part in the process. Friction forces at the die-work interface oppose the spreading of the material near the surfaces, while the material in the centre can expand more easily. The result is to create a barrel shape to the part. This effect is called barrelling in metal forging terms. Barrelling is generally undesirable and can be controlled by the use of effective lubrication. Another consideration, during hot forging manufacture, that would act to increase the barrelling effect would be the heat transfer between the hot metal and the cooler die. The metal nearer to the die surfaces will cool faster than the metal towards the centre of the part. The cooler material is more resistant to deformation and will expand less than the hotter material in the centre, also causing a barrelling effect.

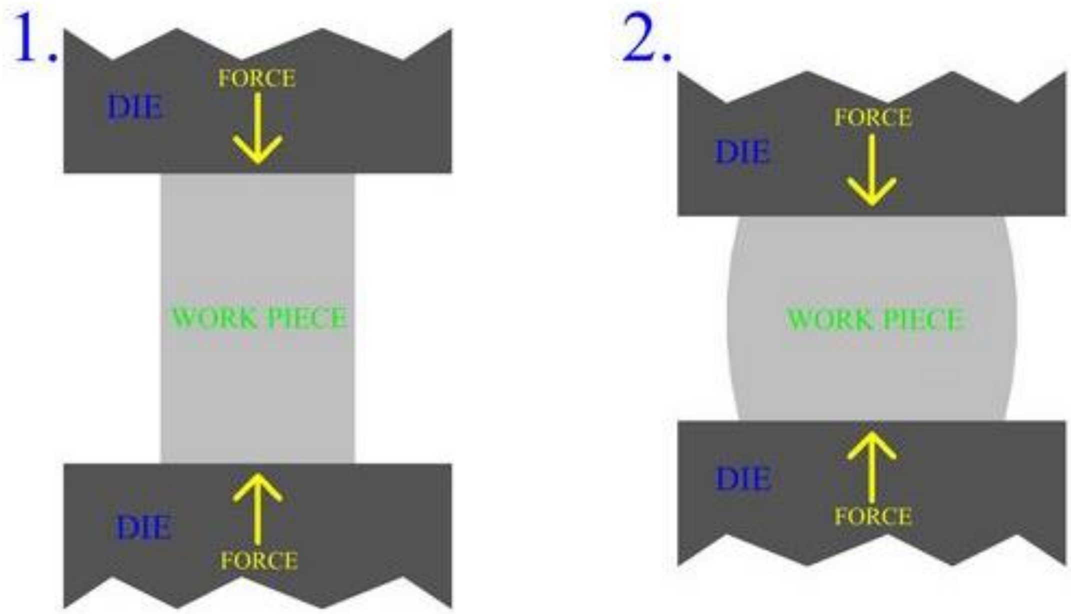


FIG 2. Upsetting in flat die forging under real conditions

1.2 Tension and Compression testing:

The evaluation and testing of mechanical behaviour of a particular sample material under various conditions of compression and tension can be performed so as to give basic material property data values which is critical for design of components and service performance assessment. The requirements for compression and tension strength values and specific methods for testing the same are specified in various standards for a wide range of materials.

The material testing can be performed on machined samples or on full-size or scaled down models of the actual components. These tests are basically performed using a UTM (Universal Testing Machine).

FIG 3. Tensile & Compression Testing Apparatus

A tensile test is basically a method for determining behaviour of materials under axial tensile loading. This test is conducted by fixturing the specimen into the test apparatus and then subsequently applying a force to the specimen by separating the testing machine crossheads. The crosshead speed can be varied in order to control the rate of strain in the test specimen. Data from the test are then used to determine tensile strength, yield strength, and the modulus of elasticity. Measurement of specimen dimensions after testing also provides reduction of area and elongation values to characterize the ductility of the material. Tensile tests can be performed on a variety of materials, including metals, plastics, fibbers, adhesives, and rubbers. Testing can be performed at sub ambient as well as elevated temperatures.

A compression test is used for determining the behaviour of materials under a compressive load. Compression tests are basically conducted by loading the test specimen between two plates, and after that applying a force to the specimen by moving the crossheads together. During the test, the specimen gets compressed, and deformation versus the applied load is plotted. The compression test is used for the purpose of determining elastic limit, proportional limit, yield point, yield strength, and (for certain materials) compressive strength.

ANALYTICAL INFORMATION:

Compressive Strength:

The compressive strength can be defined as the maximum compressive stress a material is capable of withstanding without fracture. Brittle materials fracture during testing and have a definite compressive strength value. The compressive strength of ductile materials can be determined by their degree of distortion during testing.

Elastic Limit:

Elastic limit is defined as the maximum stress that a material is capable of sustaining without permanent deformation after removal of the stress.

Elongation:

Elongation is defined as the amount of permanent extension of a specimen that has been fractured while in a tensile test.

Modules of Elasticity:

The modulus of elasticity is described as the ratio of stress (below the proportional limit) to strain, i.e., the slope of the stress-strain graph. It is considered as the measure of rigidity or stiffness of a metal.

Proportional Limit:

The proportional limit is defined as the greatest amount of stress a material is capable of reaching without any deviation from the linear relation of the stress-strain curve, i.e. without plastic deformation.

Reduction in Area:

The reduction in area is given by the difference between the original cross-sectional area of a tensile specimen and the smallest area of cross section at the after fracture following the test.

Strain:

Strain is defined as the amount of change in the shape or size of a material due to force.

Yield Point:

The yield point is given by the stress in a material (usually less than the maximum attainable stress) at which an increase in the strain occurs without an increase in stress. Only few metals have a yield point.

Yield Strength:

The yield strength is defined as the stress at which a material undergoes a specified deviation from a linear stress-strain relationship.

Ultimate Tensile Strength:

Ultimate tensile strength, or UTS, is defined as the maximum tensile stress a material is capable of sustaining without fracture. It is obtained by dividing the maximum load applied during the tensile test by the original cross sectional area of the sample.

TYPICAL APPLICATIONS:

- Tensile and compression properties of raw material for comparison to product specifications.

- Obtain material property data for finite-element modelling or other product design for desired mechanical behaviour and service performance.
- Simulation of component mechanical performance in service industries.

1.3 Objective Of The Work

The present investigation is aimed to establish a relationship between the radius of curvature of the barrel and the percentage deformation during compression testing of T-section billets.

Compression Tests are basically performed to understand and properly predict the flow behaviour of different specimens by establishing a relationship between flow stress, strain, strain rate and temperature. The experimental data obtained from this test would subsequently be utilized to form a constitutive equation relating various flow parameters and deformation parameters. The equation is subsequently used to determine the behaviour of the metal, in this case aluminium, under different conditions of loading, lubrication and putting it to appropriate usage.

The work basically involves the following steps:

- Sample preparation of Aluminium specimen in the form of T section billets.
- Characteristic study of Aluminium specimen.
- Performing compressive testing under different loading conditions on the prepared Aluminium specimens.
- Calculation of barrelling radius of T section billets under the assumption that they follow circular arc barrelling effect.
- Obtaining a regression relation between the percentage compression and the barrelling radius of the specimen.

CHAPTER 2

LITERATURE SURVEY

LITERATURE SURVEY

Many investigators have investigated the behaviour of solid cylindrical specimens during cold offset forging due to its huge technical relevance in metal forming process. A comprehensive review of the same has been published by Johnson and Mellor [2]. Another important aspect of axis-symmetric compression from the viewpoint of testing the manufacturing properties of metal is its estimation of forming limits up to plastic instability and subsequently fractures as explained by Shaw and Avery [3]. In upsetting process the presence of frictional constrains between the work-piece and the material has a pertinent effect on the plastic deformation of the former. When a solid specimen (cylinder/square billets/rectangular billets) undergoes axial compression between the bottom and punch plate, the work-piece which is in contact with the plate surfaces undergoes heterogeneous deformation which results in the phenomenon of "barrelling" of the specimen.

Friction at the faces of contact of specimen and work-piece causes a retarding effect on the plastic flow of material on the surface and its vicinity. As a result, a conical wedge like crevice of relatively un-deformed metal is formed directly below the point of compression while the rest of the specimen suffers high strains and bulges out in the form of a barrel. This demonstrates that the metal travels very easily towards the nearest free surface which is called as the point of least resistance, a well-versed principle of plastic deformation. However, the use of lubricants hugely reduces the degree of bulging and under the condition of proper ideal lubrication, bulging can be brought down to zero theoretically. The friction cannot be eliminated completely during upset forging and it is necessary to go for a correction factor for the bulging process during the designing of a die. Kulkarni and Kalpakjian [4] examined the arc of barrel, led to an assumption that it may be circular or parabolic in cross section. Meanwhile, Schey et al [5] presented a comprehensive report on the varied geometrical factors that affect the size and shape of the barrel. Banerjee [6] and Narayanasamy et al. [7] showed theoretically that barrelling radius can be expressed as a function of strain (axial) and subsequently confirmed above said through experimental analysis. Yang et al. [8] developed an upper bound theory to determine the forging load and deformed bulged profile while upset forging cylindrical billets under the dissimilar varied frictional conditions at flat die surfaces. Chen & Chen et al. [9] developed a theoretical solution for prediction of flow stresses during an upsetting operation with consideration of the barrelling effect. Gokler et al. [10] made a comprehensive study of taper upset forging using elastic plastic FEA (finite element analysis). Narayanasamy and Pandey [11] studied the effects of barrelling of aluminium solid cylinders in cold upsetting. Malayappan and Narayanasamy [12] had experimentally analysed the barrelling phenomenon under different frictional conditions at with introduction of an extrusion die constraint at one end of the work-piece. K.Manisekar and R.Narayanasamy [13] studied the phenomenon of barrelling in square billets of aluminium during cold upset forging. K.Manisekar and R.Narayanasamy [14] studied and compared the effect of barrelling in aluminium solid squares and rectangles during cold upsetting which is the basis of work to be done in this particular thesis. Vaibhav Dash [15] studied the barrelling phenomenon in hexagonal cross-section aluminium billet during cold offset forging.

CHAPTER 3

MATERIALS & METHOD

3.1 Material Used : Aluminium

FIG 4. Aluminium

Aluminium is a naturally obtained chemical element in the boron group with symbolic notation Al and 13 as its atomic number. It is a kind of silvery white, soft, ductile, malleable metal. It is the third most abundant element on earth (after oxygen and silicon), and the most abundantly available metal, in Earth's crust. Aluminium makes up to about 8% by weight of the Earth's solid crust surface. It is so chemically reactive that pure specimens are rare & limited to extremely reducing environments. Thus it is found combined with over 270 different minerals. The most abundantly available ore of aluminium is bauxite.

Aluminium is remarkable metal for its low density and for its unique ability to prevent corrosion thanks to the phenomenon of passivation. Structural components made of aluminium and its alloys are very vital to the aerospace industry & are important in various other areas of transportation and structural support materials. The most useful compounds of aluminium, are the oxides and sulphates.

Aluminium’s reactive nature makes it very useful as an additive or catalyst in chemical mixtures and reactions, including ammonium nitrate explosives, to enhance blast power.

Properties of Aluminium:

Light Weight:

Aluminium is a significantly light metal with a specific weight of just 2.7 g/cm3, about one third that of steel. For example, the use of aluminium parts in vehicles reduces its energy consumption and dead-weigh while increasing its load capacity. Its strength can be modified to the applications required by modifying the compositions of its alloys.

Corrosion Resistance:

Aluminium naturally reacts and generates a protective oxide coating and becomes highly corrosion resistant. Different types of surface treatment process such as painting, anodising or lacquering can further improve this property. It is very useful for applications where conservation and protection are required.

Electrical and Thermal Conductivity:

Aluminium is an excellent electricity and heat conductor and in with respect to its weight is twice as good a conductor as copper. This has lead to aluminium being the most commonly used metal in major power transmission lines.

Reflectivity:

Aluminium is a commendable reflector of visible light as well as of heat, and that along with its low weight, makes it ideal material for reflectors, for example, light fittings or rescue blankets.

Ductility:

Aluminium is a very ductile material and has a low melting point and density. Its ductility permits products of aluminium to be basically formed near to the very end of the product's design process.

Impermeable and Odourless:

Aluminium foil, even if it is rolled to 0.01 mm thickness, its still completely impermeable and lets neither aroma nor taste substances out. Along with that, the metal is non-toxic and releases no taste substances behind, which makes it very ideal for packaging products such as food or pharmaceuticals.

Recyclability:

Aluminium is 100% recyclable with nil downgrading of its qualities. The re-melting of aluminium too requires very little energy: only about 5% of the energy required to produce the primary aluminium metal initially is needed in the complete recycling process.

3.2 Machine Used : INSTRON (Universal Testing Machine)

FIG 5. INSTRON (Universal Testing Machine)

An UTM (Universal Testing Machine) which is also known as materials test frame/ testing machine is basically used to test the compressive and tensile properties of materials. The UTM is named so because it can perform all tests i.e. compression, bending, tension, etc. to examine any material's mechanical properties. Such machines can be classified as having single column or two columns. Extensometers and load cells are used to measure force, pressure, deformation and other parameters as the sample is tested. These machines are intensively used worldwide and are readily available in any materials testing laboratory or R&D facility.

A typical Universal testing machine basically consists of a machine/test frame, analysis simulation and control software the test jigs, fixtures, accessories and accessories which are used to hold and support the various types of test specimen.

A tension test is a destructive test in which the specimen is finally fractured beyond repair. The UTM must be capable of applying that load higher than the load required to break or fracture the specimen material so as to perform the tensile test.

The specimen of the material is usually a straight piece, uniform in cross-section over the entire test length and often with elongated ends for additional machine grips. However, the UTM is capable of holding the specimens without elongated ends also.

Before the use of digital sensor arm or non-contact extensometers, on the specimen two fine marks were made approximately near the end of uniform cross-section of the specimen and the straight line distance between these two points was defined as the "gauge length".

Gauge length is that length of the specimen which is under observation when the entire experiment on that particular specimen is performed. The specimen in the machine is held by the grips and an extensometer which is used to automatically record and plot the change in gauge length in the entire duration of the test. If also an extensometer is not fitted, the machine can itself also record distance between its cross heads in which the specimen is held. However, this procedure not only records the change in length but also measures all other elastic components of the universal testing machine and its hydraulic drive systems providing information about any type of slipping of the specimen in the grips as well.

The machine once started, it begins to apply gradually an increasing load on specimen may it be compression or elongation. Throughout the test the control system and the embedded software record the extension of the specimen and load applied on the specimen. Finally, a plot between gradually increasing load on Y-axis to that of the gradually increasing length on X-axis is obtained for the specimen. In case of compression Testing depending upon the desired percentage decrease of length of the specimen the experiment is continued till the desired percentage reduction is obtained.

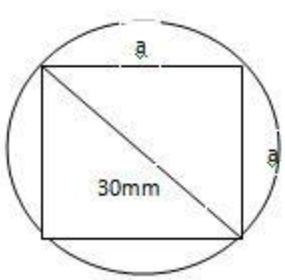
3.3 Lubricant Used : White Lithium Grease (aerosol)

Table 1 : Composition of Lubricant

COMPONENT	% by WEIGHT
Hexane isomers	40-50 %
n-Hexane	3.2 %
Heavy naphthenic petroleum distillates	10 - 20 %
Liquefied petroleum gas	35-45 %

3.4 Specimen Preparation

Compression test to be conducted using the UTM during the course of the experiment requires the manufacturing of T-section machined of commercially pure aluminium 1100 Grade. For the same a 300mm long cylindrical aluminium billet is procured having a cross-sectional diameter of 30mm. Our objective is to machine the maximum area T section from the given billet. We 1st find out the maximum area square that can be inscribed within the given circle. From the inscribed square the T section billet will be machined.



Applying Pythagoras theorem:

$$a^2 + a^2 = 30^2$$

Solving the equation we obtain a=21.2mm

FIG 6. Square section to be machined out of circular section billet

From the obtained square the T-section will be machined with the dimension below:

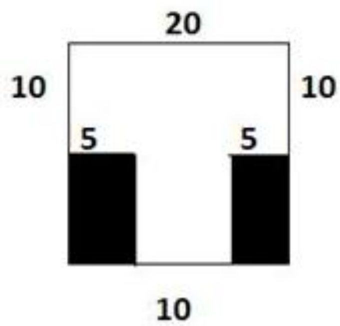


FIG 7. T-section to be machined from square billet

<u>STEP</u> 1 : Milling operation is performed on the cylindrical billet so as to obtain a square cross section from the billet. For the same the Billet is machined by using a horizontal milling machine in 2 passes on each side giving depth of 2.5mm each time. Similarly the operations are repeated for 4 faces of the square. The specimen is mounted on a 3 jaw self cantering chuck on the horizontal milling machine. For proper alignment of the work-piece the rear end of the specimen is bored to accommodate a tail-stock to it. The tail stock is used since the billet to be used is having a large length which might cause huge vibration during machining and hence might lead to breakage of the tool or the work-piece. So it is used for added support and rigidity of the specimen.

FIG 8. Cylindrical billet undergoing horizontal milling operation

FIG 9. Horizontal Milling Machine

The final specimen after the completion of the machining operation using horizontal milling machine is as below:

FIG 10. Cylindrical billet after horizontal milling operation

STEP 2 : After completion of square cross section the groove for making of T-section is done using a CNC vertical milling machine. The milling machine can be mechanically automated or digitally automated using computer numerical control. Since the operation required here is very simple the CNC milling machine is fed with a simple NC programme to perform the operation.

FIG 11. CNC Vertical Milling Machine

STEP 3: After machining operation is completed the billet is sawed into 5 specimens of length 30mm approximately using a hack-saw. A hacksaw is a hand held fine-tooth saw having a thin blade under tension in a frame, which is mostly used for metal cutting purpose. A hand-held hacksaw consists of a metal arch to hold the cutter and a handle, usually with pins for the attachment of a thin disposable blade. A screw mechanism is used so as to obtain the narrow blade under tension. The blade can be screwed with either with forward facing teeth or teeth facing away from the handle, resulting in cutting action on push and pull stroke respectively. On the push stroke, the arch is left to flex by a little amount, so as to decrease the tension on the blade. The final specimen obtained for further testing are as follows.

FIG 12. Final Specimen machined from circular billet

CHAPTER 4

RESULTS & DISCUSSION

4.1 Experimental Procedure & Data Generated

The machined aluminium specimens of T cross-section having height of 30mm is compressed under a Universal Testing Machine with White lithium Grease as the lubricant between the work surface and the specimen. All the experiments were conducted under a constant friction factor of m=0.35 as determined from Ring compression test using the same aluminium specimen and the specified Universal Testing Machine. Initially a total of 5 specimens were machines but due to misalignment in the machine struts in UTM during compression along with vertical deformation, commendable amount of sheering action also took place so the specimens were unfit for observation so were discarded. Finally a total of 3 specimens were made to undergo the experiments at various percentage of compression and the plots of load vs displacement were plotted and the corresponding data were accumulated.

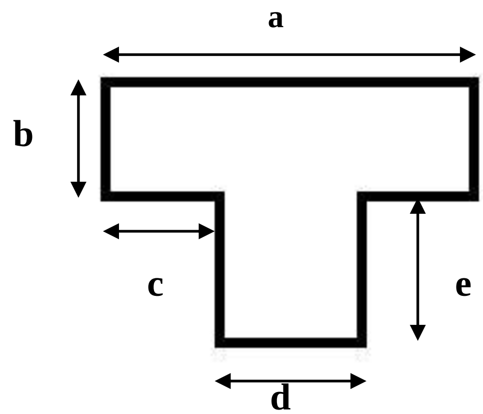


Fig 13. Initial Dimension of Specimen

Table 2 : Initial Dimension of the specimens

Specimen No.	a(mm)	b(mm)	c(mm)	d(mm)	e(mm)	Height(mm)
1	21.5	11.2	11.2	10.3	10.4	29.68
2	21.5	11.18	11.2	10.3	10.38	30.1
3	21.4	11.4	11.1	10.3	10.2	30.2
Average	**21.467**	**11.26**	**11.167**	**10.3**	**10.32**	**29.99**

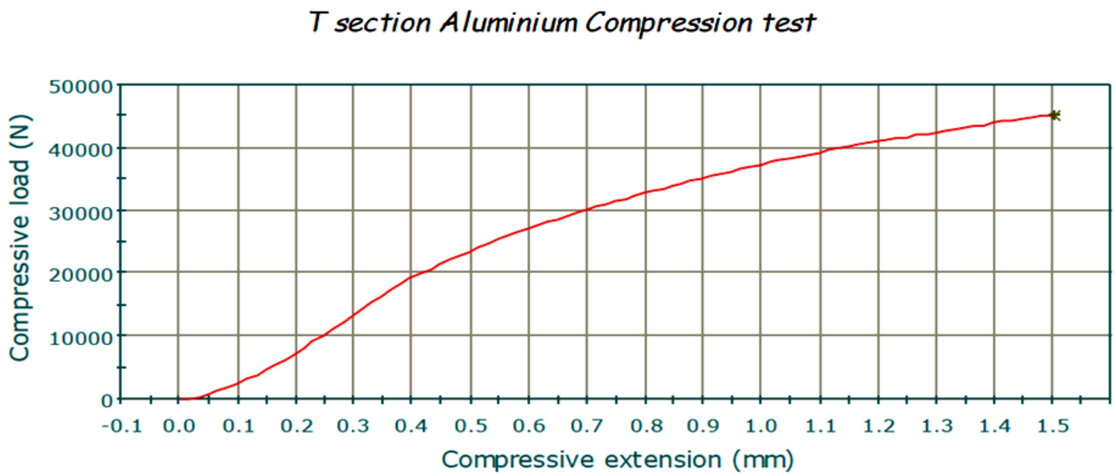
4.2 OBSERVATIONS

Table 3: Observations during compression testing using UTM

Sl no.	Compression (in mm)	Specimen 1 Comp. Load(in N)	Specimen 2 Comp. Load(in N)	Specimen 3 Comp. Load(in N)
1.	0.002	19.45231	18.32203	15.58508
2.	0.066	1,367.59	567.74388	53.00747
3.	0.132	3,914.57	2,414.21	483.17816
4.	0.2	7,209.55	4,981.92	1,955.04
5.	0.265	11,161.61	7,984.61	4,373.23
6.	0.334	15,397.75	11,412.68	7,292.91
7.	0.398	19,204.37	14,813.38	10,038.24
8.	0.464	22,180.41	17,693.91	12,794.29
9.	0.532	24,758.01	20,223.98	15,418.72
10.	0.599	27,141.47	22,516.36	17,722.86
11.	0.663	29,196.77	24,692.39	19,790.01
12.	0.73	31,048.80	26,794.41	21,812.50
13.	0.797	32,815.97	28,759.43	23,768.55
14.	0.867	34,366.24	30,618.18	25,601.84
15.	0.931	35,953.53	32,312.40	27,264.67
16.	1	37,351.57	33,875.17	28,789.94
17.	1.064	38,673.04	35,287.45	30,244.73
18.	1.133	39,868.94	36,572.59	31,533.80
19.	1.197	40,983.70	37,761.06	32,782.86
20.	1.265	42,083.80	38,887.08	34,001.85
21.	1.332	42,933.44	39,976.27	35,120.13
22.	1.4	44,040.25	40,942.93	36,156.29
23.	1.467	44,765.92	41,828.34	37,063.00
24.	1.53		42,709.57	37,975.11
25.	1.6		43,470.96	38,847.27
26.	1.663		44,266.88	39,665.44
27.	1.73		44,953.58	40,369.27
28.	1.8		45,572.04	41,100.11
29.	1.865		46,221.24	41,672.70
30.	1.933		46,746.71	42,324.56
31.	1.998		47,296.34	42,908.57
32.	2.067		47,826.66	43,531.09
33.	2.132		48,338.40	44,039.43
34.	2.197		48,821.90	44,546.32

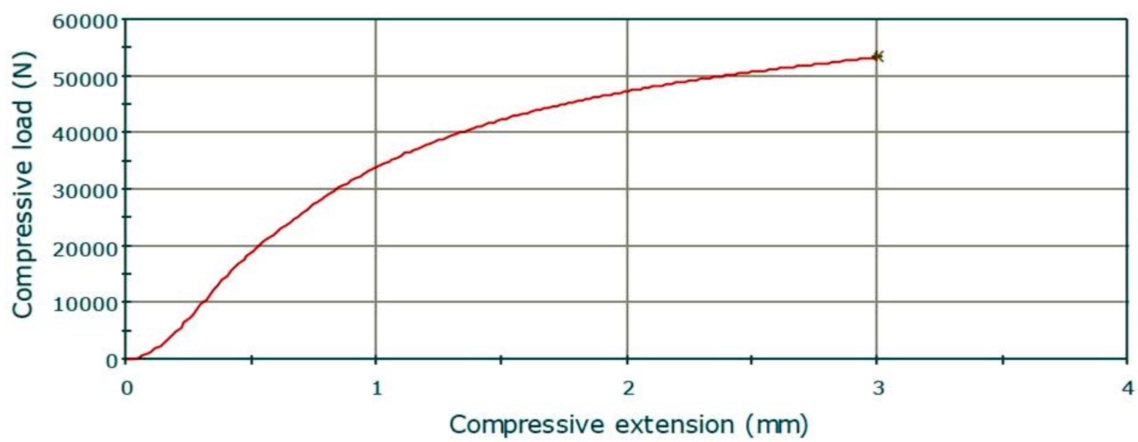
35.	2.269		49,264.96	44,989.39
36.	2.332		49,649.54	45,472.84
37.	2.397		50,089.16	45,921.95
38.	2.467		50,505.13	46,358.28
39.	2.53		50,881.53	46,810.65
40.	2.599		51,256.88	47,178.05
41.	2.663		51,586.52	47,567.68
42.	2.732		51,964.34	47,953.07
43.	2.801		52,282.96	48,297.21
44.	2.864		52,665.20	48,709.15
45.	2.933		53,023.09	49,032.92
46.	2.999		53,356.16	49,403.29
47.	3.066			49,722.25
48.	3.131			50,076.25
49.	3.197			50,351.14
50.	3.263			50,738.95
51.	3.333			51,053.01
52.	3.401			51,420.58
53.	3.466			51,737.93
54.	3.531			52,076.81
55.	3.601			52,343.24
56.	3.666			52,731.57
57.	3.729			53,013.17
58.	3.801			53,312.90
59.	3.866			53,666.63
60.	3.932			53,989.61
61.	3.996			54,316.29
62.	4.062			54,660.00
63.	4.131			54,926.38
64.	4.198			55,249.21
65.	4.263			55,564.09
66.	4.299			55,698.11
67.	4.366			56,062.31
68.	4.417			56,287.92
69.	4.449			56,428.90
70.	4.501			56,674.88

4.3 GRAPHS OBTAINED



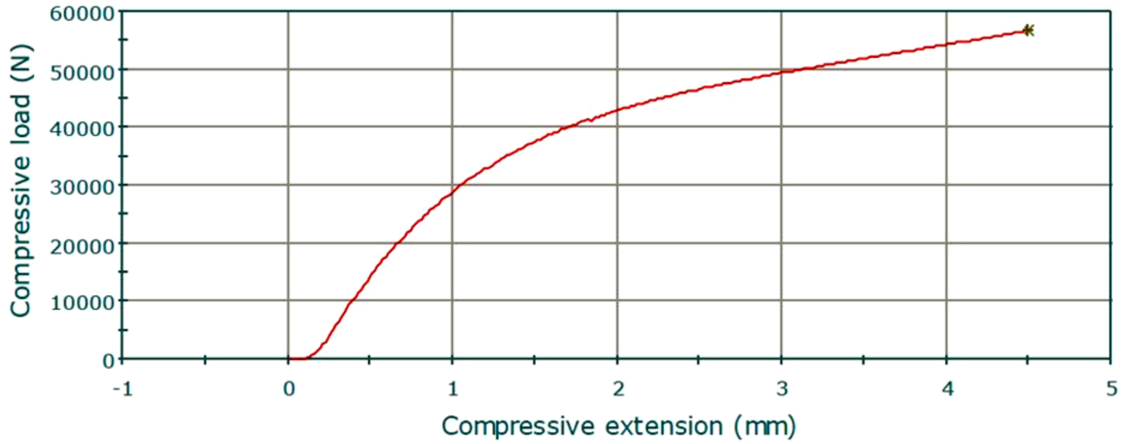
	Maximum Load (kN)	Compressive Strength (N/mm^2)
1	45.21	150.70

FIG 14. Load v/s Compression graph (Specimen 1)



	Maximum Load (kN)	Compressive Strength (N/mm^2)
1	53.42	178.07

FIG 15. Load v/s Compression graph (Specimen 2)



	Maximum Load (kN)	Compressive Strength (N/mm^2)
1	56.70	189.00

FIG 16. Load v/s Compression graph (Specimen 3)

4.4 Deformed Specimen

FIG 17. Deformed specimen after compression

4.5 Mathematical Modelling

The T-section specimen can be assumed to be a summation of 2 rectangular billets joined perpendicular to one another. In this case one being the square. The barrelling curved is assumed to follow circular arc barrelling effect having a constant radius for each surface. For obtaining the barrelling radius a formulation is derived each for the rectangular cross section and the square cross section. The barrelling effect between the joint surface between the square billet and the rectangular billet is ignored during less percentage compression.

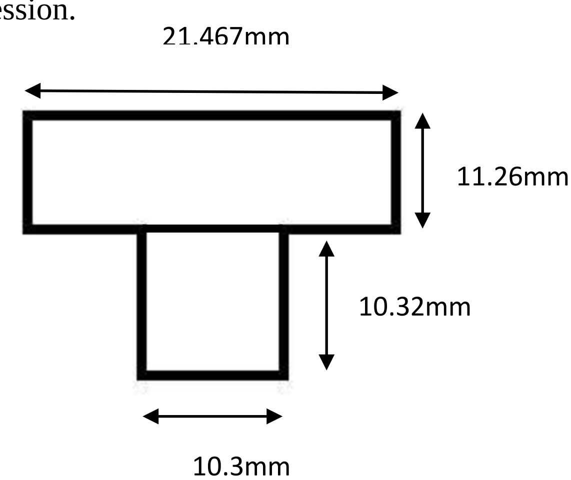


FIG 18. Average dimension of T-section Specimen

Rectangle Dimension: (21.4*11.26)mm
Square Dimension: (10.3*10.32)mm

Nomenclature

a	= side length of the rectangle along the minor axis (side of square)
b	= side length of the rectangular along the major axis
h_o	= initial height of the specimen
h_f	= height of the deformed specimen,
l_{cw}	= contact width of the square specimen
l_{bw}	= bulged width of the square specimen
A_c	= contact area of the specimen
R_1 & R_2	= radius of the barrel of curved surfaces
$l_{c1}, l_{c2}, l_{c3}, l_{c4}$	= circumferential contact lengths along the sides of the square specimen,

$l_{b1}, l_{b2}, l_{b3}, l_{b4}$	= circumferential bulged lengths along the sides of the square specimen
$l_{ac1}, l_{ac2}, l_{bc1}, l_{bc2}$	= circumferential contact length along the sides of the rectangular specimen
$l_{a1}, l_{a2}, l_{b1}, l_{b2}$	= circumferential bulged length along the sides of rectangular specimen
l_{cw1} & l_{cw2}	= contact width of the rectangular specimen parallel to major and minor axis
l_{bw1} & l_{bw2}	= bulged width of the specimen parallel to major and minor axis

Barrelling in square billets:

As explained by Manisekhar K & Narayanasamy [14], the expression of the bulging can be written as follows under the condition that this follow circular arc barrelling effect.

Volume before deformation = Volume after deformation

$$\frac{\pi}{4} * a^2 h_o = \frac{\pi}{12} * [2l_b^2 + l_c^2] h_f$$ (Under volume constancy principle) ….(Eq1)

The above equation can be written as follows:

$$\frac{h_o}{h_f} = \frac{2l_b^2 + l_c^2}{3a^2}$$ ….(Eq2)

From Narayanasamy R and Pandey K.S,[10] the radius of curvature of barrel is as follows:

$$x = R-(R^2-h_f^2/4)^{0.5}$$ ….(Eq3)

Where,

$$x = (l_{bw} - l_{cw})/2$$

Simplifying the expression (Eq3), the expression for the barrel radius R can be obtained neglecting x^2 term (because the quantity of the x is very less)
Therefore

$$R = h_f^2/8x$$ ….(Eq4)

Otherwise,

$$R = h_f^2/4(l_{bw} - l_{cw})$$ ….(Eq5)

Multiplying by h^2 both in numerator and denominator of the expression (Eq5), the following expression can be obtained:

$$R^{0.50} = (h_f/h_o)\, ho/[2(l_{bw} - l_{cw})^{0.5}]$$ ….(Eq6)

From expression (Eq2) and (Eq6), the barrel radius becomes as follows:

$$R^{0.50} = \frac{h_o}{2(l_{bw} - l_{cw})^{1/2}} \frac{3a^2}{[2l_b^2 + l_c^2]}$$ ….(Eq7)

The right hand side of the equation (Eq7) is the new geometrical shape factor for square billets.

Barrelling in rectangular billets:

The expression of bulging can be written as follows under the condition that this follows circular arc barrelling effect.

Volume before deformation = Volume after deformation

$$\pi/4[(2a/\pi)+(2b/\pi)]^2 h_o = \pi/12[2[(2l_a + 2l_b)/\pi]^2 + [(2\, l_{ac} + 2l_{bc})/\pi]^2] h_f$$

Simplifying the above equation the following equation is obtained:

$$(\pi/4)(a+b)^2 h_o = (\pi/12)[2(l_a+l_b)^2 + (l_{ac}+l_{bc})^2] h_f$$ ….(E1)

The above equation (E1) can be written as follows:

$$[h_o/h_f] = [2(l_a+l_b)^2 + (l_{ac}+l_{bc})^2]/[3(a+b)^2]$$ ….(E2)

From Narayanasamy R and Pandey K.S,[10] the radius of curvature of barrel is as follows:

$$x_1 = R_1 - (R_1{}^2 - h_f^2/4)^{0.5}$$

where: $x_1 = (l_{bw1} - l_{cw1})/2$ ….(E3)

Simplifying the expression (E3), the expression for the barrel radius R1 can be obtained neglecting x^2 term (because the quantity of the x is very less)

Therefore $R_1 = h_f^2/8x$

Otherwise $R_1 = h_f^2/4(l_{bw1} - l_{cw1})$ ….(E4)

Multiplying by h_o^2 both in numerator and denominator of the expression (E4), the following expression can be obtained:

$$R_1^{0.50} = (h_f/h_o)\, ho/[2(l_{bw1} - l_{cw1})^{0.5}]$$ ….(E5)

From expression (E2) and (E5), the barrel radius becomes as follows:

$$R_1^{0.50} = \frac{h_0}{2(l_{bw1} - l_{cw1})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$ ….(E6)

Similarly, the expression for the barrel radius in a plane parallel to the minor axis can be written as:

$$R_2^{0.50} = \frac{h_0}{2(l_{bw2} - l_{cw2})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$ ….(E7)

4.6 Calculation :

After compression testing the dimensions are as follows.

Table 4: Specimen Specifications after compression:

Dimensions	***Specimen 1***	***Specimen 2***	***Specimen 3***
% Reduction in height(in %)	5	10	15
Initial Height (h_o) (in mm)	29.69	30.1	30.2
New height (h_f) (in mm)	28.5	27	25.5
Initial side length of Square specimen (a) (in mm)	10.26	10.26	10.26
Bulged width of square specimen (l_{bw}, l_b) (in mm)	10.42	10.9	11.2
Contact width of square specimen (l_{cw}, l_c) (in mm)	10.28	10.4	10.2
Initial Side length of rectangle specimen along major axis (a) (in mm)	21.46	21.46	21.46
Initial Side length of rectangle specimen along minor axis (b) (in mm)	11.26	11.26	11.26
Bulged side length along major axis in rectangle specimen(l_a)(in mm)	21.9	22.2	23.2
Bulged side length along minor axis in rectangle specimen(l_b)(in mm)	11.2	11.9	12
Contact side length along major axis in rectangle specimen(l_{ac})(in mm)	21.75	21.9	22.1
Contact side length along minor axis in rectangle specimen(l_{bc})(in mm)	11.17	11.8	11.8

Specimen 1 :

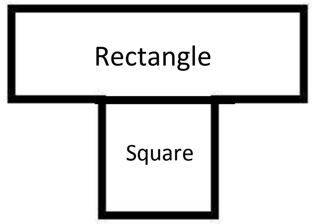


FIG 19. T-section specimen assumed as a summation of square and rectangular billet

Barrelling in square portion:

As derived in above mathematical modelling:

$$R^{0.50} = \frac{h_o}{2(l_{bw} - l_{cw})^{1/2}} \frac{3a^2}{[2l_b^2 + l_c^2]}$$

Substituting the values of the above terms from the table 2 we get

$$R^{0.5} = \frac{29.68}{2(10.42 - 10.28)^{0.5}} * \frac{3 * 10.26^2}{(2 * 10.42^2 + 10.28^2)}$$

Therefore, $\boldsymbol{R_0 = 1575.05\ mm}$

Barrelling in rectangular cross-section:

Radius of barrel parallel to major axis:

$$R_1^{0.50} = \frac{h_0}{2(l_{bw1} - l_{cw1})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

Substituting the values of the above terms from the table 2 we get

$$R_1^{0.5} = \frac{29.68}{2(21.9 - 21.75)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (21.9 + 11.2)^2 + (21.75 + 11.17)^2)}$$

Therefore, $\boldsymbol{R_1 = 1486.9\ mm}$

Radius of barrel parallel to minor axis:

$$R_2^{0.50} = \frac{h_0}{2(l_{bw2} - l_{cw2})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

Substituting the values of the above terms from the table 2 we get

$$R_2^{0.5} = \frac{29.68}{2(11.2 - 11.17)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (21.9 + 11.2)^2 + (21.75 + 11.17)^2)}$$

Therefore, $\boldsymbol{R_2 = 7434.78\ mm}$

Specimen 2 :

Barrelling in square portion:

As derived in above mathematical modelling:

$$R^{0.50} = \frac{h_o}{2(l_{bw} - l_{cw})^{1/2}} \frac{3a^2}{[2l_b^2 + l_c^2]}$$

Substituting the values of the above terms from the table 2 we get

$$R^{0.5} = \frac{30.1}{2(10.9 - 10.4)^{0.5}} * \frac{3 * 10.26^2}{(2 * 10.9^2 + 10.4^2)}$$

Therefore, $\boldsymbol{R_0 = 384.4\ mm}$

Barrelling in rectangular cross-section:

Radius of barrelling parallel to major axis:

$$R_1^{0.50} = \frac{h_0}{2(l_{bw1} - l_{cw1})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

Substituting the values of the above terms from the table 2 we get

$$R_1^{0.5} = \frac{30.1}{2(22.2 - 21.9)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (22.2 + 11.9)^2 + (21.9 + 11.7)^2)}$$

Therefore, $\boldsymbol{R_1 = 665.57\ mm}$

Radius of barrel parallel to minor axis:

$$R_2^{0.50} = \frac{h_0}{2(l_{bw2} - l_{cw2})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

Substituting the values of the above terms from the table 2 we get

$$R_2^{0.5} = \frac{30.1}{2(11.9 - 11.7)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (22.2 + 11.9)^2 + (21.9 + 11.7)^2)}$$

Therefore, $\boldsymbol{R_2 = 998.36\ mm}$

Specimen 3 :

Barrelling in square portion:

As derived in above mathematical modelling:

$$R^{0.50} = \frac{h_o}{2(l_{bw} - l_{cw})^{1/2}} \frac{3a^2}{[2l_b^2 + l_c^2]}$$

Substituting the values of the above terms from the table 2 we get

$$R^{0.5} = \frac{30.2}{2(11.2 - 10.2)^{0.5}} * \frac{3 * 10.26^2}{(2 * 11.2^2 + 10.2^2)}$$

Therefore, $\boldsymbol{R_0 = 166.458\ mm}$

Barrelling in rectangular cross-section:

Radius of barrelling parallel to major axis:

$$R_1^{0.50} = \frac{h_0}{2(l_{bw1} - l_{cw1})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

Substituting the values of the above terms from the table 2 we get

$$R_1^{0.5} = \frac{30.2}{2(23.2 - 22.1)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (23.2 + 12)^2 + (22.1 + 11.8)^2)}$$

Therefore, $\boldsymbol{R_1 = 150.81\ mm}$

Radius of barrel parallel to minor axis:

$$R_2^{0.50} = \frac{h_0}{2(l_{bw2} - l_{cw2})^{1/2}} \frac{3[(a+b)^2]}{\{[2(l_a + l_b)^2 + (l_{ac} + l_{bc})^2]\}}$$

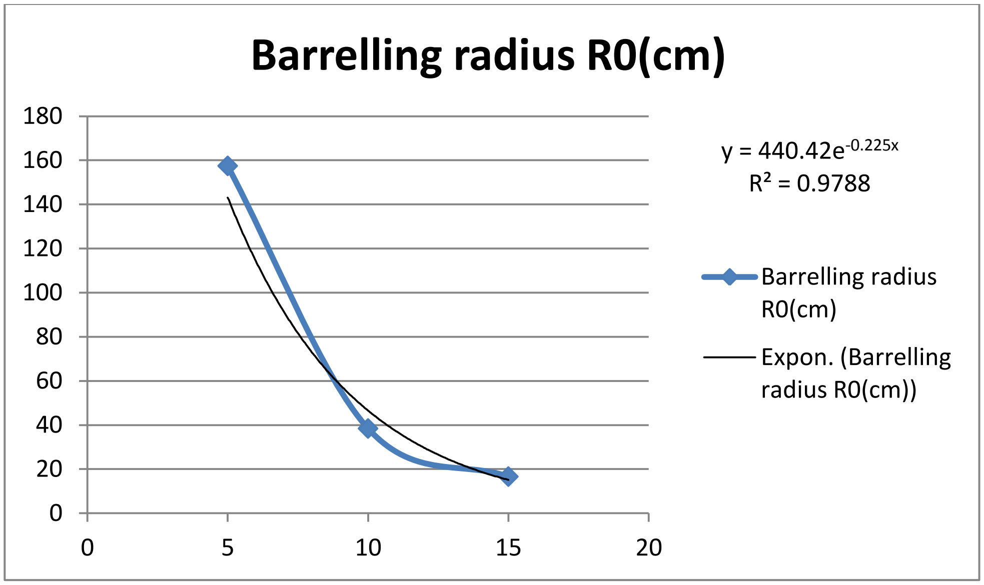
Substituting the values of the above terms from the table 2 we get

$$R_2^{0.5} = \frac{30.2}{2(12 - 11.8)^{0.5}} * \frac{3 * (21.456 + 11.316)^2}{(2 * (23.2 + 12)^2 + (22.1 + 11.8)^2)}$$

Therefore, $\boldsymbol{R_2 = 829.46\ mm}$

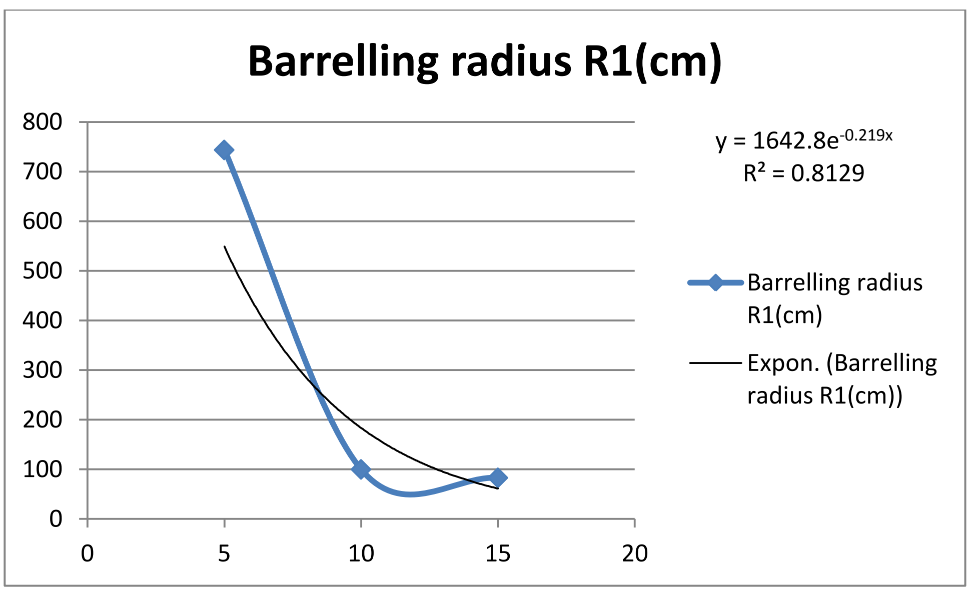
4.7 Regression analysis

The relation between barrelling radius (R_0, R_1, R_2) and percentage deformation is generalized using Regression exponential curve. The regression exponential curve can be plotted by feeding the values obtained in the experiment to the Microsoft Office excel. Initially a table is formed showing variation in barrelling radius with respect to the percentage deformation. Then a scatter chart is plotted assigning these values. Then a trend-line is set using polynomial function as the trend.



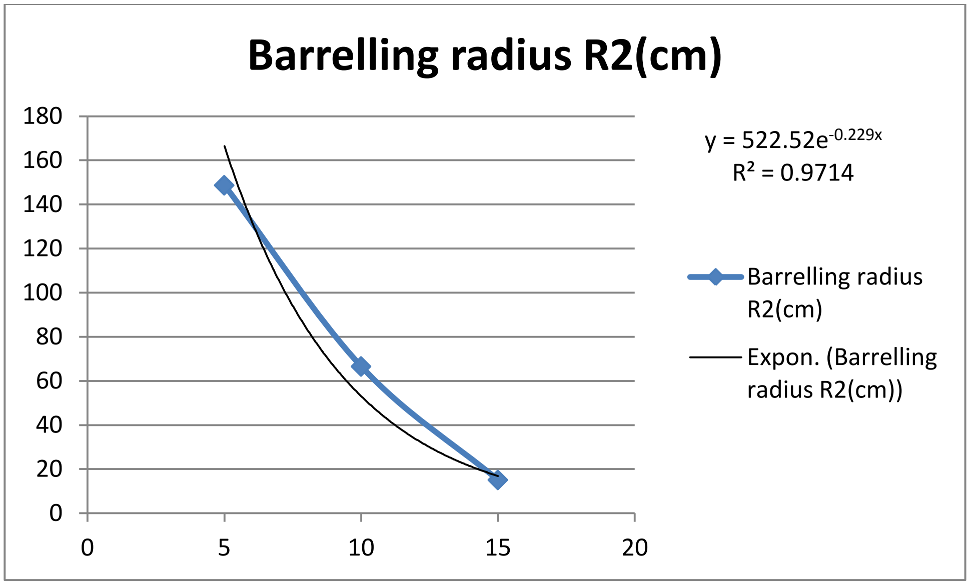
% Compression	Barrelling radius R0(cm)
5	157.5
10	38.44
15	16.64

FIG 20. Regression curve between Barrelling Radius (R_0) and percentage compression



% Compression	Barrelling radius R1(cm)
5	743.47
10	99.84
15	82.946

FIG 21. Regression curve between Barrelling Radius (R_1) and percentage compression



% deformation	Barrelling radius R2(cm)
5	148.69
10	66.55
15	15.1

FIG 22. Regression curve between Barrelling Radius (R_2) and percentage compression

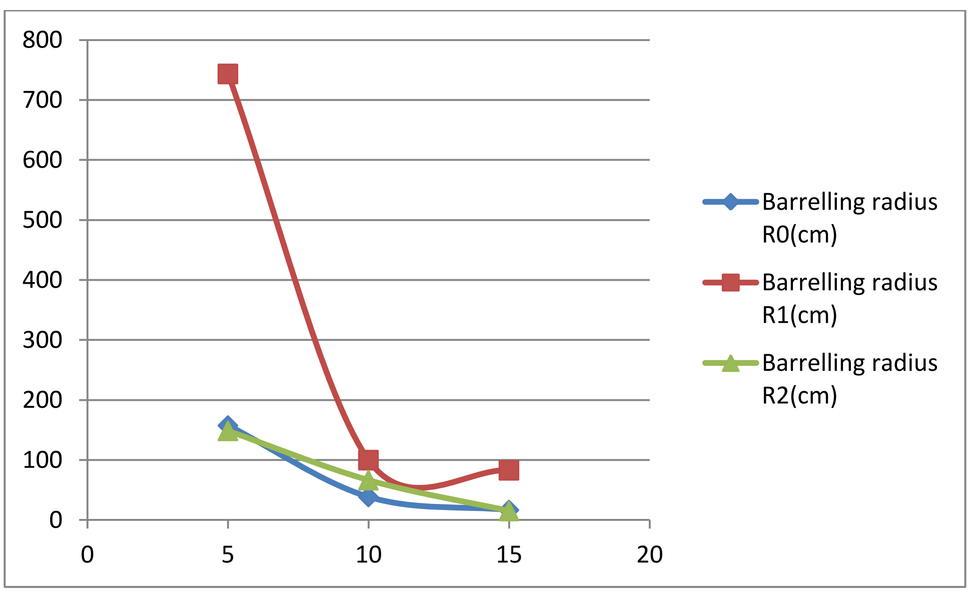


FIG 23. Plot of change in barrelling radius (R_0, R_1, R_2) of three different surfaces of T-section specimen with respect to change in percentage compression

CHAPTER 5

CONCLUSION

CONCLUSION:

Compression test of Aluminium Billets of T Cross-Section was conducted under constant friction condition (Friction factor=0.35) and at room temperature ($27^{o}C$) with uniaxial loading in Universal Testing Machine. It has been concluded that the obtained radius of barrel and the regression exponential value of radius of barrel is in close proximity with each other. So the variation of barrelling radius along the faces of T-section billet can be generalized using the Regression exponential equation is proposed as follows:

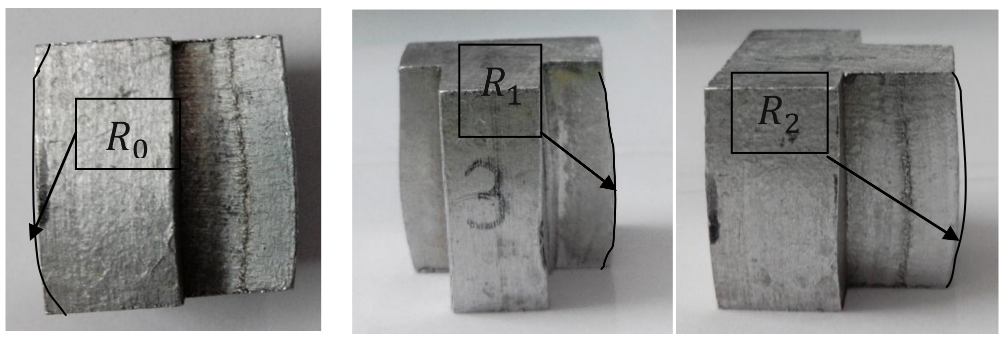


FIG 24. Barrelling Radius of a T-section Specimen

- $R_0 = 440.42 * e^{-0.225x}$
- $R_1 = 1642.8 * e^{-0.219x}$
- $R_2 = 522.52 * e^{-0.229x}$

Where,

R_0= Barrelling radius of the square cross-section of T-section billet.

R_1= Barrelling radius along the major axis of rectangular cross section of T section billet.

R_2= Barrelling radius along the minor axis of rectangular cross section of T section billet.

x = Percentage deformation of billet (in a scale of 0-100).

The slight variation in the theoretical and experimental values is due to the following assumption considered during the mathematical modelling:

1. The barrelling phenomenon follows circular arc barrelling effect.
2. A T-section billet is considered as a summation of a square and a rectangular billet.
3. The effect on the rectangle billet on the square billet and vice versa is negligible.

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